FIELD OF THE INVENTION

This invention relates to thin walled polyethylene containers. The containers are useful for packaging foods such as cottage cheese and ice cream.

BACKGROUND OF THE INVENTION

Plastic food containers are ubiquitous items of commerce. Ideally, these containers should have thin walls (preferably from about 0.35 millimeters to 1.30 millimeters thick) in order to reduce the amount of plastic used to produce the container. However, the containers must also have strength at high temperatures (for example, to permit a container to be filled with ricotta cheese at temperatures over 80°C) and at low temperatures (so as to withstand the impact when a filled ice cream container is dropped). Such "thinwalled" containers are typically prepared by injection molding.

Injection molding equipment is widely available and is well described in the literature. The machinery is highly productive, with molding cycle times often being measured in seconds. These machines are also very expensive so there is a need to maximize productivity (i.e. minimize cycle times) in order to control overall production costs. Productivity may be influenced by the choice of plastic resin used in the process. In particular, a resin which flows well is desirable to reduce cycle times.

Flow properties are typically influenced by molecular weight (with low molecular weight resin having superior flow properties in comparison to high molecular weight resin) and molecular weight distribution (with

narrow molecular weight resins generally producing molded parts with reduced warpage in comparison to broad molecular weight distribution resins). Copolymer resins of similar molecular weight and molecular weight distribution generally have higher hexane extractables levels than homopolymer resins, making them less satisfactory for food applications.

The strength of the finished product over a range of temperatures is also important. The strength of a finished product may often be increased by increasing the molecular weight of the resin used to prepare it, but this is done at the expense of machine productivity. Similarly, the use of a copolymer resin will often improve the impact strength and flexibility of a product in comparison to the use of homopolymer, but at the expense of extractables content. Thus, a suitable food container which is made at high "machine productivity" yet also demonstrates good strength properties at high and low temperatures would be a useful addition to the art.

SUMMARY OF THE INVENTION

The present invention provides a container having a nominal volume of from 100 mL to 12 L which is prepared by injection molding of ethylene copolymer resin, said container having a Vicat softening point of greater than 121°C and an average test drop height point of greater than 2.5 feet as determined by ASTM D5276 wherein said ethylene copolymer resin is characterized by having:

i) a density of from 0.950 g/cc to 0.955 g/cc;

ii) a viscosity at 100,000 s^{-1} and 280°C of less than 3.5 Pascal seconds;

iii) a molecular weight distribution, Mw/Mn of from 2.2 to 2.8; and

iv) a hexane extractables content of less than 0.5 weight %.

Preferred containers also have a total impact energy required for base failure of greater than 0.2 foot-pounds at -20°C as determined by Instrumented Impact Testing according to ASTM D3763 (with an instrument sold under the tradename "INSTRON-DYNATUP").

DETAILED DESCRIPTION

We have discovered that thinwalled polyethylene containers having a Vicat softening point of greater than 121°C and an average test drop height of greater than 2.5 feet may be prepared from a linear polyethylene copolymer resin having all of the following essential characteristics:

1) a density of from 0.950 to 0.955 g/cc;

2) a melt index I_2, of from 30 to 100 g/10 min as measured by ASTM D1238 at 190°C;

3) a molecular weight distribution (Mw/Mn) of from 2.2 to 2.8;

4) an apparent viscosity at 100,000 s^{-1} and 280°C of less than 3.5 Pascal seconds; and

5) a hexane extractables content of less than 0.5 weight %.

Each of these characteristics is described below.

The density of a polyethylene copolymer is influenced by the molecular structure of the copolymer. "Linear" homopolymers of ethylene are rigid molecules that solidify as crystalline resins. Linear ethylene resins which also have a narrow molecular weight distribution (Mw/Mn, discussed below) are further characterized by having sharp (distinct)

melting points, which is desirable for injection molding processes. However, the impact strength of such resins (especially at low temperatures) is poor. The density of a linear ethylene homopolymer having a narrow molecular weight distribution is generally greater than 0.958 grams per cubic centimeter ("g/cc").

The density of a linear ethylene polymer may be reduced by incorporating a comonomer (such as butene, hexene, or octene) into the polymer structure. The comonomers produce "branches" which inhibit crystal packing and the resulting copolymers generally display improved impact strengths in comparison to homopolymers. For example, flexible polyethylene films (not a part of this invention) are typically made from copolymers having more than 8 mole % comonomer and a density from about 0.905 to 0.935 g/cc.

The copolymer used in this invention contains a comparatively small but critical amount of comonomer. The linear ethylene copolymers must have a density of from 0.950 to 0.955 g/cc. This very specific and narrow density range is essential in order to obtain high machine productivity and high strength containers. For the purpose of this invention, the density of the resin is determined according to ASTM standard test procedure D792.

The melt index (I_2, as determined by ASTM D1238) of the resins used to prepare the container of this invention must be from 30 to 100 g/10 min. The preferred melt index range is from 50 to 90 g/10 min. The melt index of a polyethylene copolymer resin is also established by the molecular structure. Molecular weight is particularly important and is

inversely related to melt index I_2. That is, an increase in molecular weight will generally reduce the ability of the copolymer to flow (and thus cause an decrease in I_2). High melt indices (lower molecular weights) are desirable to increase machine productivity but high molecular weight is desirable for strength.

The ethylene copolymer resins used to prepare the containers of this invention are further characterized by having a molecular weight distribution (as determined by dividing the weight average molecular weight "Mw" by the number average molecular weight "Mn") of from 2.2 to 2.8.

Molecular weight determinations (Mw and Mn) are made by high temperature gel permeation chromatography (GPC) using techniques which are well known to those skilled in the art. It will be recognized by those skilled in the art that different GPC equipment and/or analytical techniques sometimes result in slightly different absolute values of weight average molecular weight (Mw) and number average molecular weight (Mn) for a given resin. Therefore, the resin used in this invention is defined by the ratio Mw/Mn.

We have determined that resins having a Mw/Mn of from 2.2 to 2.8 (and the density, I_2, viscosity characteristic and hexane extractables level specified for this invention) provide containers having excellent strength and allow very good productivity.

The present containers are fabricated from ethylene copolymer resin which has apparent viscosity of less than 3.5 Pascal seconds when subjected to a shear rate of 100,000 s^{-1} at 280°C.

We have determined that this viscosity range provides strong containers and high machine productivity. Lower viscosity resins typically produce containers having inferior strength properties. Viscosity is measured according to ASTM D3835.

Finally, this invention uses a resin having a hexane extractables content (as determined by ASTM D5227) of less than 0.5 weight %.

The containers of this invention must be made from ethylene copolymer resin which satisfies all of the above criteria. Such resin may be prepared using the polymerization catalyst and polymerization process which is described in United States Patent 6,372,864 (Brown et al.). Further details of the invention are provided in the following non-limiting examples.

EXAMPLES

Part 1: **Test Procedures Used in The Examples**

1. "Instrumented Impact Testing" was completed using a commercially available instrument (sold under the tradename "INSTRON-DYNATUP") according to ASTM D3763.

2. Melt Index: I_2 and I_6 were determined according to ASTM D1238.

3. Stress exponent is calculated by $\frac{\log(I_6/I_2)}{\log(3)}$.

4. Number average molecular weight (Mn), weight average molecular weight (Mw), z-average molecular weight (Mz) and polydispersity (calculated by Mw/Mn) were determined by high temperature Gel Permeation Chromatography ("GPC").

5. Flexural Secant Modulus and Flexural Tangent Modulus were determined according to ASTM D790.

6. Elongation, Yield and Tensile Secant Modulus measurements were determined according to ASTM D636.

7. Hexane Extractables were determined according to ASTM D5227.

8. Densities were determined using the displacement method according to ASTM D792.

9. "Drop Testing" was completed according to ASTM D5276.

Part 2: <u>Preparation of an Injection Molded Container</u>

For the resins in Example 1, containers were prepared using an injection molding apparatus sold under the tradename Husky LX 225 P60/60 E70. The mold used for these samples was a 4-cavity mold making containers with a nominal outside diameter of 4.35 inches (11.0 cm), a thickness of 0.025 inches (0.6 mm) and a volume of 750 mL. Details of the Husky LX 225 P60/60 E70 thin wall injection molding (TWIM) machine are below:

<u>Husky X 225 P60/50 E70</u>

Clamp:	250 tons
Plunger:	50 mm
Screw:	70 mm
Screw L/D Ratio:	25:1
Melt Channel Diameter:	8 mm

Conventional barrel temperatures for this apparatus typically range from 150 to 300°C. For the resins in Example 1, barrel temperatures ranged from 200 to 250°C, depending on the position in the barrel. Details on temperatures and other molding conditions are tabulated in Example 1.

Part 3: <u>Preparation of an Injection Molded Lid</u>

The machine sold under the tradename Husky LX 225 P60/60 E70 was also used for the resins in Example 2. The mold used for these

samples was a 6-cavity mold making round lids for the containers produced in Example 1. The lids produced have a nominal outside diameter of 4.68 inches (11.9 cm) and a thickness of 0.04 inches (1.0 mm). Barrel temperatures were cooler than for the resins in Example 1, at 200 to 230°C. Details on temperatures and other molding conditions are tabulated in Example 2.

Example 1

Inventive resins E1 and E2 were characterized and compared to three commercially available resins used in this application (Table 1). E1 is a higher molecular weight, broader molecular weight distribution resin while E2 provides the lowest molecular weight and narrowest molecular weight distribution of the five resins studied. The data in Table 1 were collected using conventional ASTM testing techniques on resin pellets and compression molded plaques.

TABLE 1

Characterization of Experimental Container Resins E1& E2 vs. Benchmarks*

	Units	C1	E1	C2	C3	E2
Density	g/cm^3	0.9493	0.9516	0.9513	0.9536	0.9517
I_2	g/10 min	56	69	73	86	95
I_6	g/10 min	265	268	280	323	352
Stress Exponent		1.43	1.24	1.23	1.21	1.19
I_{21}	g/10 min	836	838	772	805	834
Melt Flow Ratio		15	12	10.5	9.3	8.81
Viscosity @100000 sec^{-1} @250°C	Pa-sec	3.6	3.9	4.2	3.8	3.9
Viscosity @100000 sec^{-1} @280°C	Pa-sec	3.1	3.4	3.4	3.4	3.4
No. Ave. Mol. Wt. (Mn)	x 10^{-3}	10.3	13.1	9.8	10.4	13.9
Wt. Ave. Mol. Wt. (Mw)	x 10^{-3}	40.8	34.6	35.3	34.0	32.3
Z Ave. Mol. Wt. (Mz)	x 10^{-3}	152.5	75.8	77.2	70.4	59.7
Polydispersity Index		3.96	2.64	3.58	3.27	2.32
Hexane Extractables	%	0.81	0.24	0.78	0.70	0.29
Melting Point	°C	126.7	128.9	128.1	128.0	129.0
Crystallinity	%	71.7	75.9	69.3	69.0	81.4
Vicat Softening Point	°C	119	124	121	122	124
Shore D Hardness		66.4	67.2	66.3	66.1	67.2
Flex. Sec Modulus, 1%	MPa	934	1128	1177	1208	1161
Flex. Sec Modulus, 2%	MPa	809	994	1024	1058	1010

Flexural Strength	MPa	27.9	35.2	33.1	35.6	35.5
Yield Elongation	%	6	15	7	8	11
Yield Strength	MPa	23.5	26.8	25.3	27.8	26.3
Ultimate Elongation	%	7	24	7	8	12
Ultimate Strength	MPa	23.7	25	25.3	27.8	26.3
Tensile Impact	$ft\text{-}lb/in^2$	9.39	38	23.5	21.7	22.6
Whiteness Index		79.21	91.3	87.58	90	91.38
Yellowness Index		-3.31	-7.23	-6.22	-6.56	-7.04

*Physical test data from compression molded plaques.
C1 is a polyethylene resin sold under the tradename Equistar H5057.
C2 is a polyethylene resin sold under the tradename SCLAIR 2815.
C3 is a polyethylene resin sold under the tradename SCLAIR 2717.

The data in Table 1 show that the experimental resins provide by far the lowest hexane extractable content, making them suitable for food applications. Their higher crystallinity, Vicat softening point, Shore D hardness and Flexural Modulus suggest their suitability for higher temperature filling and capping operations, (e.g. ricotta cheese). This data set also shows that the experimental resins should provide equivalent toughness and better color in comparison to incumbent products used in this market.

Container products were produced using the five resins in Table 1. They were produced on the Husky injection molding unit described above using the conditions listed in Table 2.

TABLE 2

Husky Injection Molding Machine Settings and Variables for Molding Container Resins

	Units	C1	E1	C2	C3	E2
Resin Specs						
MI	g/10 min	56	69	73	86	95
Density	g/cm^3	0.9493	0.9516	0.9513	0.9536	0.9517
S.Ex.		1.43	1.24	1.23	1.21	1.19
M/C Settings						
Fill pressure	%	78	78	78	78	78
High Speed enable start	mm	70	70	70	70	70
High Speed enable stop	mm	30	32	30	34	36
Pullback	mm	12	12	12	12	25
Gate heat	% on	75	75	75	75	50
Barrel temperature Zone 1	°C	200	200	200	200	200
Barrel temperature Zone 2	°C	210	210	210	210	210
Barrel temperature Zone 3	°C	220	220	220	220	220

Barrel temperature Zone 4	°C	230	230	230	230	230
Barrel temperature Zone 5	°C	250	250	250	250	250
Variables						
Shot weight	g	104.09	104.36	104.25	104.47	104.77
Cycle time	sec	5.78	5.80	5.88	5.81	5.80
Injection time	sec	0.36	0.39	0.41	0.39	0.40
Screw run time	sec	2.11	2.03	2.03	2.06	2.07
Screw back pres	psi	245	245	248	254	248
Ext. drive pres	psi	1059	1115	1131	1085	1045
Max. inj. Pres	psi	2236	2219	2230	2217	2205
Hold pressure Zone 1	psi	1088	1087	1087	1088	1088
Hold pressure Zone 2	psi	635	636	637	631	630
Hold pressure Zone 3	psi	301	303	304	302	302
Barrel temperature Zone 1	°C	200	200	200	197	200
Barrel temperature Zone 2	°C	211	211	211	208	211
Barrel temperature Zone 3	°C	221	221	221	221	221
Barrel temperature Zone 4	°C	230	230	230	230	230
Barrel temperature Zone 5	°C	251	251	251	251	251

In a conventional injection molding cycle, the molten resin is injected into a closed mold which is water cooled. It is desirable to maximize the productivity of these expensive machines, while also reducing energy requirements. In order to achieve this, the resin must have excellent rheological properties so that the resin flows sufficiently to completely fill the mold.

Table 2 provides data which show that the resin E2 from Example 1 requires lower pressure to mold a part. As a result, the barrel temperatures may be lowered in order to reduce energy consumption while maintaining cycle time. Conversely, temperatures could be maintained with a reduced cycle time, thus increasing the molding unit's unit productivity.

Conventional resins used in thin wall injection molding (TWIM) container applications are typically of medium to high density and also exhibit higher molecular weight than resins used in thin wall injection molding (TWIM) lid applications. The typical tradeoff in these applications is that if a stiffer product is desired, density is increased at the expense of

product toughness. Similarly, if better product toughness is desired, the density of the resin is reduced somewhat and molecular weight of the resin is also increased, lowering the melt index and making the resin more difficult to process.

Extensive physical testing of the containers yielded the data in Table 3. It is clear that in general, the superior properties of the experimental resins predicted in Table 1 follow through to the injection molded parts. What is surprising is that the experimental resins, (while providing equivalent stiffness, as indicated by the retention of density for various positions on the part relative to the maximum density available, i.e. pellet density), also provide enhanced toughness, both at low and ambient temperature. This "decoupling" of the stiffness/toughness balance appears to apply at both lower and higher melt index. This is illustrated by the part drop test data, as defined by ASTM D5276. It shows that the experimental resins provide a pass at nearly twice the height of the incumbent resins.

TABLE 3

Injection Molded Containers

		Units	C1	E1	C2	C3	E2
Pellet	Density	g/cm^3	0.9493	0.9516	0.9513	0.9536	0.9517
	Melt Index I_2	g/10 min	56	69	73	86	95
	Melt Index I_6	g/10 min	265	268	280	323	352
	Stress Exponent		1.43	1.24	1.23	1.21	1.19
Part	Density - gate	g/cm^3	0.941	0.9429	0.9424	0.9428	0.943
	mid floor	g/cm^3	0.9399	0.9419	0.9411	0.9412	0.942
	step	g/cm^3	0.94	0.9421	0.9413	0.9414	0.9421
	skirt	g/cm^3	0.9405	0.9427	0.9412	0.943	0.9428
	Melt Index I_2	g/10 min	55	71	70	81	93
	Melt Index I_6	g/10 min	266	281	269	296	328
	Stress Exponent		1.44	1.25	1.23	1.18	1.15
Tensile Properties							
MD	Elong. at Yield	%	17	14	17	17	14
	Yield Strength	MPa	18	21.1	19.9	19.9	21.5
	Ultimate Elong.	%	650	1093	1138	391	1077
	Ultimate Strength	MPa	18.8	19.7	18.8	13.9	16.9

TD	Elong. At Yield	%	15	12	15	16	13
	Yield Strength	MPa	10.8	13.2	11.6	12	12.9
	Ultimate Elong.	%	185	423	337	197	325
	Ultimate Strength	MPa	10.8	13.2	11.6	12	12.9
Impact T sting							
	Max. Load @ 23°C on wall	lb	121	118	122	119	117
	Total Energy @ 23°C on wall	ft-lb	2.85	3.59	2.04	1.82	3.06
	Max. Load @ -20°C on wall	lb	165	153	159	151	148
	Total Energy @ -20°C on wall	ft-lb	2.84	2.44	2.52	2.05	3.25
	Max. Load @ 23°C on bottom	lb	14	11	12	12	24
	Total Energy @ 23°C on bottom	ft-lb	0.51	0.42	0.4	0.42	0.46
	Max. Load @ -20°C on bottom	lb	19	10	15	13	30
	Total Energy @ -20°C on bottom	ft-lb	0.11	0.31	0.11	0.16	0.23
Initial Tear Resistance							
MD	Load At Max.	N	66.4	68.3	72.7	61	54.5
	Stress At Max.	N/mm	103.1	107.2	112.9	95.5	89.5
	% Strain At Max.	%	16.7	4.5	6.6	4.3	2.5
TD	Load At Max.	N	89	94	95.2	82.6	64.5
	Stress At Max.	N/mm	139.1	148.1	153.6	126.1	105
	% Strain At Max.	%	66.4	68.7	74.1	38.9	5.5
	Whiteness Index (part)		77.58	88.84	86.57	88.32	87.26
	Yellowness Index (part)		-4.76	-8.3	-8.82	-9.76	-7.89
Part Drop Test (Bruceton Staircase)							
	Ave. Pass Drop Height	ft	1.6	2.7	1.5	1.3	2.6
	Max Pass Height	ft	3	5	3	3	5
	Min Pass Height	ft	1	1	1	1	1
	Part Shrinkage, 72 hours	%	2.15	1.82	2.12	2.11	1.80

Example 2

Parallel to Example 1, Table 4 provides characterization results of experimental resins E3 and E4 in comparison to four competitive grades in the TWIM lid market. In similar fashion to the container resins, the experimental lid resins have significantly lower extractables content making them well suited for food applications. They also provide equivalent crystallinity at a lower melting point along with a higher Vicat softening point temperature and equivalent Shore D hardness. This combination of properties suggests lids produced from these resins would be suitable for hot fill applications, such as those described above for the experimental container resins. They also appear to have equivalent or slightly better toughness and equivalent color properties.

TABLE 4

Characterization of Experimental Lid Resins E3 & E4 vs. Benchmarks*

	Units	C4	C5	C6	E3	C7	E4
Density (g/cm^3)		0.9311	0.9319	0.9354	0.9324	0.9308	0.9321
I_2	g/10 min	117	118	132	150	156	168
I_6	g/10 min	454	458	525	535	600	670
Stress Exponent		1.24	1.24	1.28	1.16	1.23	1.26
I_{21}	g/10 min	665	844	820	840	845	846
Melt Flow Ratio		5.7	7.2	6.1	5.57	5.4	5.06
Viscosity @100000 sec^{-1} @230°C	Pa-sec	3.6	3.5	2.9	3.7	3.3	2.8
Viscosity @100000 sec^{-1} @250°C	Pa-sec	3.2	3	2.7	3.3	2.8	2.6
No. Ave. Mol. Wt. (Mn)	x 10^{-3}	10.0	9.1	8.3	10.6	10.5	9.1
Wt. Ave. Mol. Wt. (Mw)	x 10^{-3}	30.0	29.7	30.7	28.6	28.4	29.2
Z Ave. Mol. Wt. (Mz)	x 10^{-3}	60.6	60.4	74.3	51.2	55.9	67.3
Polydispersity Index		3.00	3.27	3.72	2.70	2.70	3.20
Hexane Extractables	wt %	3.50	3.27	4.49	0.87	2.26	1.30
Melting Point	°C	122.2	123.6	125.8	119.5	124.0	119.0
Crystallinity	%	44.0	52.4	56.6	63.7	55.9	56.8
Vicat Softening Point	°C	90	87	96	104	96	101
Shore D Hardness		57.1	59.5	60.3	59.6	59.6	60.2
Flex. Sec Modulus, 1%	MPa	475	627	631	569	498	534
Flex. Sec Modulus, 2%	MPa	444	577	580	513	464	486
Flex. Strength	MPa	17.1	21.3	21	20.5	17.7	19.9
Yield Elongation	%	11	10	11	18	13	17
Yield Strength	MPa	15	15.7	16.6	16.6	15	16.2
Ultimate Elongation	%	40	36	76	54	47	46
Ultimate Strength	MPa	12.9	12.7	11.1	9.3	12.9	12.6
Tensile Impact	ft-lb/in^2	34.9	37.8	40.1	49.8	42.8	43.6
Whiteness Index		80.08	87.25	90.29	84.17	78.29	85.15
Yellowness Index		-9.05	-10.15	-10.72	-9.31	-8.22	-9.98

*Physical test data from compression molded plaques.
C4 is a polyethylene resin sold under the tradename SCLAIR 2813.
C5 is a polyethylene resin sold under the tradename Equistar 5947.
C6 is a polyethylene resin sold under the tradename DNDA 1081.
C7 is a polyethylene resin sold under the tradename Dowlex 2507.

Lid products were produced using the six resins in Table 4. They were produced on the Husky injection molding unit mentioned above under the conditions listed in Table 5. These data indicate that the experimental resins process very similarly to the incumbent resins. In addition, the resin E4 requires lower pressure to mold a part. As a result, the barrel temperatures may be lowered in order to reduce energy consumption while maintaining cycle time, or cycle time reduced at the same temperature.

TABLE 5

Husky Injection Molding Machine Settings and Variables for Molding Lid Resins

	Units	C4	C5	C6	E3	C7	E4
Resin Specs							
MI	g/10 min	117	118	132	150	156	168
Density	g/cm^3	0.9311	0.9319	0.9354	0.9324	0.9308	0.9321
S.Ex.		1.24	1.24	1.28	1.16	1.23	1.26
M/C Settings							
Fill pressure	%	65	55	55	50	55	50
Pullback	mm	0	10	10	10	10	10
Hold pressure Zone 1	%	20	20	20	20	20	20
Hold pressure Zone 2	%	15	15	15	15	15	15
Hold pressure Zone 3	%	10	10	10	10	10	10
Barrel temperature Zone 1	°C	200	200	200	200	200	200
Barrel temperature Zone 2	°C	210	210	210	210	210	210
Barrel temperature Zone 3	°C	220	220	220	220	220	220
Barrel temperature Zone 4	°C	230	230	230	230	230	230
Barrel temperature Zone 5	°C	230	230	230	230	230	230
Variables							
Shot weight	g	55.85	55.73	55.73	55.74	55.73	55.80
Cycle time	sec	4.82	4.84	4.83	4.84	4.83	4.81
Injection time	sec	0.37	0.37	0.36	0.38	0.37	0.36
Screw run time	sec	1.40	1.32	1.40	1.40	1.44	1.56
Screw back pres	psi	257	255	258	255	257	255
Ext. drive pres	psi	867	888	827	882	818	767
Max. inj. Pres	psi	851	845	778	832	770	725
Hold pressure z.1	psi	545	426	426	376	422	375
Hold pressure z.2	psi	271	271	271	270	270	271
Hold pressure z.3	psi	220	221	223	220	220	221
Barrel temperature Zone 1	°C	200	197	199	197	200	200
Barrel temperature Zone 2	°C	209	207	209	208	211	211
Barrel temperature Zone 3	°C	220	219	219	220	221	221
Barrel temperature Zone 4	°C	230	227	228	229	230	230
Barrel temperature Zone 5	°C	230	229	229	231	230	230

Extensive physical testing of the lids yielded the data in Table 6. These data show that the experimental resins E3 and E4 retain their stiffness properties and provide excellent toughness. Additionally, these experimental resins provide vastly superior clarity. This clarity is apparent for the two experimental resins based on testing using ASTM D1003 (Table 6). Thus, text placed a short distance behind lids made from any of the incumbent resins is not even discernible, let alone legible, yet can be clearly read when placed a similar distance behind a lid made from the

either of the experimental resins. At smaller distances, such as might occur in packaging a product like yogurt or coffee with a printed foil seal beneath the lid, this effect is less dramatic. However, the improved clarity would allow a customer to more easily read the label and thus make the product more attractive.

TABLE 6

Injection Molded Lids

	Units	C4	C5	C5	E3	C7	E4
Pellet Density	g/cm^3	0.9311	0.9319	0.9354	0.9324	0.9308	0.9321
Melt Index I_2	g/10 min	117	118	132	150	156	168
Melt Index I_6	g/10 min	454	458	525	535	600	670
Stress Exponent		1.24	1.24	1.28	1.16	1.23	1.26
Part Density - gate	g/cm^3	0.9267	0.9269	0.9264	0.9276	0.9259	0.9274
mid floor	g/cm^3	0.9256	0.9264	0.9256	0.9267	0.9253	0.9265
step	g/cm^3	0.9254	0.926	0.9254	0.9265	0.9249	0.9265
skirt	g/cm^3	0.9257	0.9268	0.9261	0.9276	0.9258	0.9271
Melt Index I_2	g/10 min	118	114	129	148	152	171
Melt Index I_6	g/10 min	458	444	515	534	571	676
Stress Exponent		1.24	1.24	1.26	1.17	1.21	1.25
Tensile Properties							
MD Elong. at Yield	%	23	22	21	19	24	20
Yield Strength	MPa	10.4	11.2	12.4	12	10.6	11.6
Ultimate Elong.	%	238	209	318	337	287	312
Ultimate Strength	MPa	9	9.4	9.6	9.8	8.9	9.6
TD Elong. at Yield	%	21	20	20	20	22	20
Yield Strength	MPa	10.8	11.5	12	11.9	10.2	11.9
Ultimate Elong.	%	94	149	469	103	141	234
Ultimate Strength	MPa	9.8	8.6	8.8	8.6	8.4	9
Impact Testing							
Max. Load @ 23°C on Gate	lb	99	97	105	107	101	105
Total Energy @ 23°C on Gate	ft-lb	3.06	3.07	3.27	3.19	3.14	3.2
Max. Load @ -20°C on Gate	lb	149	144	151	103	114	152
Total Energy @ -20°C on Gate	ft-lb	4.9	5.13	5.23	2.86	4.17	5.4
Max. Load @ 23°C off Gate	lb	93	92	87	94	100	93
Total Energy @ 23°C off Gate	ft-lb	2.62	2.74	2.7	2.92	3.04	2.82
Max. Load @ -20°C off Gate	lb	141	153	145	149	160	130
Total Energy @ -20°C off Gate	ft-lb	4.61	5.64	4.95	5.41	5.65	5.14
Initial Tear Resistance							
MD Load At Max.	N	55.3	57.7	63	65.6	57.4	61.2
Stress At Max.	N/mm	77.8	81.1	89.3	92.2	80.6	86.1
% Strain At Max.	%	17.3	23.2	41.3	15.9	42.1	16.8
TD Load At Max.	N	53.3	54.8	61.1	61.8	55.8	59.6
Stress At Max.	N/mm	79.5	81.1	89.7	92.1	82.6	90.2
% Strain At Max.	%	44.2	32.8	37	35.9	62.2	26.4
Whiteness Index WI, (part)		72.49	75.26	81.2	77.36	74.52	75.64
Yellowness Index, YI (part)		-15.94	-12.76	-15.56	-8.62	-13.69	-8.57
Gloss	%	54	54	54	55	54	55
Haze	%	87.3	93.9	94.5	78	90.9	81.1
Clarity	%	13	20	7	98	15	98
Part Shrinkage, 96 hours	%	1.82	1.82	1.87	1.78	1.81	1.79